TECHNICAL REPORT ARLCB-TR-80009

A WIDE RANGE K EXPRESSION FOR THE C-SHAPED SPECIMEN

J. KAPP
J. C. Newman
J. H. Underwood

March 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
LARGE CALIBER WEAPON SYSTEMS LABORATORY
BENET WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

9 June 1980

ERRATA SHEET
(Change Notice)

C1 TO: TECHNICAL REPORT ARLCB-TR-80009

A WIDE RANGE K EXPRESSION FOR THE C-SHAPED SPECIMEN

by

J. A. Kapp
J. C. Newman, Jr.
J. H. Underwood

Remove the Report Documentation Page, DD Form 1473,
from the above subject publication dated March 1980,
and insert new Report Documentation Page inclosed.

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND

LARGE CALIBER WEAPON SYSTEMS LABORATORY

BENET WEAPONS LABORATORY

WATERVLIET, N. Y. 12189

REPORT DOCUMENTATION PAGE

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
ARLCB-TR-80009		

4. TITLE (and Subtitle)
A WIDE RANGE K EXPRESSION FOR THE C-SHAPED SPECIMEN

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
J. A. Kapp, J.H. Underwood
J.C. Newman Jr.- NASA Langley Research Ctr.
Hampton, VA 23665

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Benet Weapons Laboratory
Watervliet Arsenal, Watervliet, NY 12189
DRDAR-LCB-TL

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
AMCMS No. 5397OM63500
PRON No. 1A924154GGGG

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Armament Research & Development Command
Large Caliber Weapon Systems Laboratory
Dover, New Jersey 07801

12. REPORT DATE
March 1980

13. NUMBER OF PAGES
15

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Presented to ASTM Taskgroup E24.01.05, 30 Oct 79, Pittsburgh, PA.
To be published in the Journal of Testing and Evaluation.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Calibration
Fracture Mechanics
Fracture Properties
Fracture Testing
Toughness

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
A new expression has been developed to calculate K for the C-shaped specimen over a wider range of specimen parameters, namely a/W, X/W, and r_1/r_2, than had previously been available. The rationale used to derive the expression was to utilize known stress intensity factor solutions for short and deep cracks to develop a nondimensional form of K which approaches finite values as a/W goes to both zero and one. Numerical K solution results from prior work were then nondimensionalized to this form with the finite limiting

20. ABSTRACT (Cont'd)

values, and the dependence of K on a/W was determined by multi-variable, linear regression. The final expression agrees with the numerical K solutions within $\pm$ 1.0% for $.45 \leq$ a/W $\leq$ .55 for all r_1/r_2 and X/W of either 0 or .5; within $\pm$ 1.5% for $.2 \leq$ a/W $\leq$ 1 for all r_1/r_2 and X/W equal to 0 or .5; and within about $\pm$ 3% for $.2 \leq$ a/W $\leq$ 1 for all r_1/r_2 and $0 \leq$ X/W $\leq$ 1. The accuracy of this expression will allow expanded use of the C-shaped specimen for R-curve determination and fatigue crack growth rate testing.

CONTENTS

TABLES

ILLUSTRATION

INTRODUCTION

Recently the C-shaped specimen has been included as a standard specimen in ASTM Test for Plane-Strain Fracture Toughness of Metallic Materials, E-399-78. The stress intensity factor (K) expression for the C-shaped specimen in the ASTM Test was obtained by Underwood and Kendall [1] by fitting a three parameter expression to boundary collocation results. The expression applies over the following ranges of the three parameters:

$$0.3 \leq a/W \leq 0.7 \quad , \quad 0 \leq X/W \leq 0.7 \quad , \quad 0 \leq r_1/r_2 \leq 1.0 \quad ,$$

where a is crack length, W is specimen depth, and r_1 and r_2 are respectively the inner and outer radius of the specimen as shown in Figure 1. For fatigue crack growth rate testing and R-curve measurements using the C-shaped specimen, K must be known over a wider range of a/W than that of the current expression. The purpose of this paper is to develop a wider range K expression for the C-shaped specimen.

PROCEDURE

Srawley [2] has developed wide range K expressions for two K_{Ic} specimens used in ASTM Method E-399-78, the compact specimen and the bend specimen. An approach similar to that used by Srawley was used here to develop a K expression for the C-shaped specimen. Since K varies from zero to infinity as a/W goes from zero to one for the C-shaped specimen, it is very difficult to determine an expression which accurately represents the variation in K with crack depth. This problem can be circumvented by using a nondimensional form of K which has the correct limiting values as a/W approaches both zero and one. Known K solutions for a finite crack in a semi-infinite plane and

1

for a semi-infinite crack in a semi-infinite plane were applied as limiting cases for short and deep cracks respectively. This resulted in an expression which, for both limits of a/W, converges to the correct limiting value. The a/W dependence between the limits was described by fitting a polynomial in a/W to the available K solutions [3-6] for the C-shaped specimen.

Because the C-shaped specimen is intended for use with a range of hollow cylinder geometries, the K expression must account for load eccentricity, X/W, and the radius ratio, r_1/r_2, in addition to a/W. The X/W dependence was determined by examining the limiting K solutions, and the r_1/r_2 dependence was found using the numerical K results.

First we consider the deep crack limit which is a function of the resultant normal force, P, and the resultant moment, M, acting on the uncracked ligament of the specimen. If P is assumed to act at the center of the uncracked ligament with dimension (W-a), the stress intensity factor is given as [7]:

$$K_I = 0.464 \frac{2P}{B\sqrt{\pi(W-a)}} \quad . \tag{1}$$

For the case of the resultant bending moment, M, K is [7]:

$$K_I = 3.975 \frac{M}{B(W-a)^{3/2}} \quad . \tag{2}$$

The total stress intensity factor as the crack depth approaches through penetration of the specimen is the superposition of equations (1) and (2). By calculating M in terms of C-shaped specimen parameters and after some algebra, the limiting value as a/W approaches 1, of the familiar nondimensional form of K is determined.

2

$$\lim_{a/W \to 1} \frac{KB\sqrt{W}}{P} = \frac{1.325(3X/W + 1.926 + 1.104a/W)}{(1-a/W)^{3/2}} \tag{3}$$

By rearranging equation (3), a nondimensional form of K which approaches a finite value for all X/W and r_1/r_2 as a/W goes to 1 is obtained.

$$\lim_{a/W \to 1} \frac{KB\sqrt{W}(1-a/W)^{3/2}}{P(3X/W + 1.926 + 1.104a/W)} = 1.325 \tag{4}$$

To determine a nondimensional form of stress intensity factor that has a finite limit for short cracks a different K solution must be used, the well known Wigglesworth solution,

$$K_I = 1.12 \ \sigma\sqrt{\pi a} \tag{5}$$

where σ in this case is the total stress acting perpendicular to the plane of the crack at r_1 in an uncracked C-shaped specimen. This stress has two components, a normal component and a bending component, of which the bending stress is strongly dependent on the curvature (r_1/r_2) of the specimen. Since the deep crack limit is unaffected by r_1/r_2, the effects of curvature must. disappear as the relative crack depth increases to 1. The r_1/r_2 dependence cannot be totally accounted for by analysis of the short crack limit. Therefore, the stress σ, used in equation (5) is initially calculated assuming no effects of curvature and the r_1/r_2 dependence will be determined separately.

Using linear bending theory and basic mechanics of materials concepts, the stress σ is easily determined in terms of C-shaped specimen parameters. Substituting this in equation (5), the limiting value of the familiar non-dimensional form of stress intensity factor is

3

$$\lim_{a/W \to 0} \frac{KB\sqrt{W}}{P} = \frac{2.24\sqrt{\pi}\ \sqrt{a/W}(3X/W + 2 + a/W)}{(1-a/W)^2} \tag{6}$$

Upon rearranging equation (6) a nondimensional form of K is obtained that has a finite limit for all X/W as a/W goes to zero.

$$\lim_{a/W \to 0} \frac{KB\sqrt{W}(1-a/W)^2}{P\sqrt{a/W}(3X/W + 2 + a/W)} = 2.24\sqrt{\pi} \tag{7}$$

Although the form of equations (4) and (7) are somewhat different, some changes can be made to both equations that do not change these limits. Because $\sqrt{a/W}$ approaches 1 as a/W approaches 1, this term may be included in the demoninator of equation (4) without disturbing that limit. Also for a/W close to zero, $(1-a/W)^2 = (1-a/W)^{3/2}$ to a first order approximation, thus $(1-a/W)^{3/2}$ can replace $(1-a/W)^2$ in the numerator of equation (7) leaving that limit unchanged. The remaining difference between the two equations does affect the limits. Since the form of equation (4) gives a better description of the X/W dependence of the collocation solutions than that of equation (7), it was decided to use a simplified form of equation (4) as the form of nondimensional K used to fit the collocation data. Thus the final form of the wide range expression is:

$$\frac{KB\sqrt{W}(1-a/W)^{3/2}}{P(a/W)^{1/2}(3X/W + 1.9 + 1.1a/W)} = f(a/W) \cdot g(r_1/r_2\ ,\ a/W) \tag{8}$$

The functions f and g were then fit to the collocation data with the conditions that for the limits a/W $\to$ 1 and a/W $\to$ 0 the product of f and g equals the values in equations (4) and (7) respectively.

4

The function g was difficult to determine exactly. For all r_1/r_2 as a/W approaches 1, g must approach 1, and as a/W approaches 0, g is the ratio of the stress normal to the plane of the crack at r_1 using curved beam theory to that stress acting at r_1 using straight beam theory. This ratio was determined and found to be highly complex and has a strong dependence on X/W in addition to r_1/r_2. Therefore, g was developed by fitting a polynomial that describes the r_1/r_2 dependence of the available collocation results for the standard C-shaped specimens, that is for X/W = 0 and 0.5. For a/W ranging from .2 to 1, g was found to be:

$$g(r_1/r_2, a/W) = 1 + .25(1-a/W)^2(1-r_1/r_2) \quad . \tag{9}$$

The function f was determined from the available collocation data and the deep crack limit for the standard C-shaped specimens. Using multivariable linear regression, these data were fit to the following cubic polynomial, for a/W from 0.2 to 1.

$$f(a/W) = 3.74 - 6.30 \, a/W + 6.32(a/W)^2 - 2.43(a/W)^3 \tag{10}$$

COMPARISON WITH COLLOCATION DATA

To illustrate the goodness of fit of equation (10), values of f(a/W) calculated from the collocation results for standard specimens are compared in Table 1 to the corresponding values determined from equation (10). For comparison we have defined an error function E, which is the difference between the value of f(a/W) from equation (10) and the value f_c from the collocation results divided by the value of f_c.

5

Based on the comparisons in Table 1 and on the information from the limit solutions, equation (10) agrees with all these solutions within ± 1.5% for $.2 \leq a/W \leq 1$ and within ± 1% for $.45 \leq a/W \leq .55$ for all r_1/r_2 and X/W of either 0 or .5.

Comparisons are made in Table 2 between equation (10) and other collocation results for nonstandard specimens. Analysis of the relative errors in these cases indicate that the derived K expression should not be used for specimens with X/W values greater than about 1. As X/W becomes large, the bending component of the stress distribution becomes dominant. Since the bending component is significantly affected by the curvature of the specimen, the variation in K could have been explained by the function g derived above. However, g was not obtained exactly, but by fitting to the numerical solutions for the standard specimens, so good agreement can not be expected for X/W larger than 0.5.

RESULTS

To calculate K using equations (8), (9), and (10) is cumbersome. To simplfy K determination, equations (8), (9), and (10) can be arranged to a more convenient form:

$$K = \frac{P}{B\sqrt{W}} [3 \; X/W + 1.9 + 1.1 \; a/W][1 + .25(1-a/W)^2(1-r_1/r_2)]F(a/W) \quad , \quad (11)$$

where

$$F(a/W) = \frac{\sqrt{a/W}}{(1-a/W)^{3/2}} (3.74 - 6.30 \; a/W + 6.32(a/W)^2 - 2.43(a/W)^3)$$

Numerical values of F(a/W) have been determined for two ranges of a/W and are presented in Tables 3 and 4.

Equation (11) agrees with the numerical solutions available [3-6] within $\pm$ 1.0% for .45 $\leq$ a/W $\leq$ .55 for all r_1/r_2 and X/W of either 0 or .5, within $\pm$ 1.5% for .2 $\leq$ a/W $\leq$ 1 for all r_1/r_2 and X/W equal to 0 or .5; and within about $\pm$ 3% for .2 $\leq$ a/W $\leq$ 1 for all r_1/r_2 and 0 $\leq$ X/W $\leq$ 1. The K expression of equation (11) is as accurate as that which is currently given in ASTM Method E-399-78. The new expression can be used for other fracture testing over a wider range of a/W than that of the current expression.
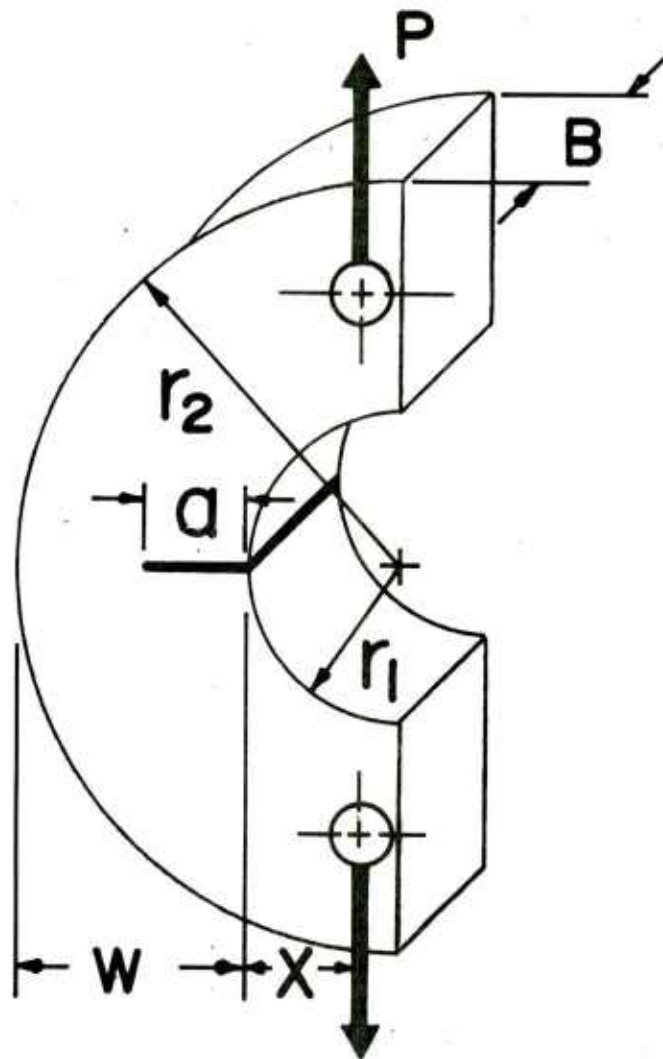
Fig. 1. The C-Shaped Specimen, Indicating Geometric Parameters

TABLE 1. COMPARISON OF f(a/W) VALUES FROM EQ. (10) WITH CORRESPONDING VALUES, f_c, FROM COLLOCATION AND LIMIT SOLUTIONS

$$E = \frac{f(a/W) - f_c}{f_c}$$

SPECIMENS WITH X/W = 0:

a/W	f(a/W)	r_1/r_2: 1.0 (3) f_c	E	0.4 (3) f_c	E	0.675 (6) f_c	E	0.1 (6) f_c	E
0.2	2.713	2.713	.000	2.726	-.005	-	-	-	-
0.3	2.353	2.343	.002	2.319	.015	-	-	-	-
0.4	2.076	2.074	.001	2.053	.011	2.067	.004	2.059	.008
0.5	1.866	1.871	-.002	1.865	.001	1.861	.003	1.869	-.002
0.6	1.710	1.712	-.001	1.716	-.004	1.702	.005	1.713	-.002
0.7	1.593	1.585	.005	1.593	.000	-	-	-	-
0.8	1.501	1.483	.012	1.492	.006	-	-	-	-
1.0	1.330	1.326	.003	1.326	.003	-	-	-	-

SPECIMENS WITH X/W = 0.5:

a/W	f(a/W)	r_1/r_2: 1.0 (3) f_c	E	0.4 (3) f_c	E	0.675 (5) f_c	E	0.338 (5) f_c	E
0.2	2.713	2.698	.006	2.753	-.015	-	-	-	-
0.3	2.353	2.339	.006	2.344	.004	-	-	-	-
0.4	2.076	2.075	.001	2.072	.002	2.073	.001	2.078	-.001
0.5	1.866	1.873	-.003	1.877	-.006	1.871	-.003	1.879	-.007
0.6	1.710	1.713	-.002	1.722	-.007	1.702	.005	1.721	-.006
0.7	1.593	1.586	.004	1.596	-.001	-	-	-	-
0.8	1.501	1.483	.012	1.493	.005	-	-	-	-
1.0	1.330	1.326	.003	1.326	.003	-	-	-	-

TABLE 2. COMPARISON OF $f(a/W)$ VALUES FROM EQ. (10) WITH CORRESPONDING VALUES, f_c, FROM REFERENCE 4

$$E = \frac{f(a/W) - f_c}{f_c}$$

X/W = 0.560 ; r_1/r_2 = 0.481

a/W	f_c	E
.275	2.492	-.016
.366	2.137	.007
.458	1.939	.002
.549	1.801	-.010
.641	1.679	-.011

X/W = 0.983 ; r_1/r_2 = 0.584

a/W	f_c	E
.281	2.463	-.019
.421	2.086	-.028
.562	1.831	-.036
.702	1.540	.033

X/W = 0.712 ; r_1/r_2 = 0.500

a/W	f_c	E
.250	2.553	-.012
.375	2.098	.013
.500	1.879	-.007
.625	1.634	.023

X/W = 1.600 ; r_1/r_2 = 0.667

a/W	f_c	E
.20	2.854	-.052
.30	2.416	-.027
.40	2.160	-.041
.50	1.914	-.026
.60	1.690	.011

10

TABLE 3.   VALUES OF $F(a/W)$ FOR THE RANGE OF a/W USED IN K_{Ic} TESTING

a/W	F(a/W)	a/W	F(a/W)
.450	3.23	.500	3.73
.455	3.27	.505	3.79
.460	3.32	.510	3.85
.465	3.37	.515	3.91
.470	3.42	.520	3.97
.475	3.47	.525	4.03
.480	3.52	.530	4.10
.485	3.57	.535	4.17
.490	3.62	.540	4.24
.495	3.68	.545	4.31
		.550	4.38

TABLE 4.   VALUES OF $F(a/W)$ FOR WIDE RANGE OF a/W

a/W	F(a/W)	a/W	F(a/W)
.20	1.70	.60	5.24
.25	1.94	.65	6.42
.30	2.20	.70	8.11
.35	2.49	.75	10.70
.40	2.82	.80	15.01
.45	3.23	.85	23.15
.50	3.73	.90	42.53
.55	4.38	.95	119.90

REFERENCES

1. Underwood, J. H. and Kendall, D. P., "Fracture Toughness Testing Using the C-Shaped Specimen," _Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632_, W. F. Brown, Jr., and J. G. Kaufman, Eds., American Society for Testing and Materials, 1977, pp. 25-38.

2. Srawley, J. E., "Wide Range Stress Intensity Factor Expressions for ASTM E-399 Standard Fracture Toughness Specimens," _International Journal of Fracture Mechanics_, Vol. 12, June 1976, p. 475.

3. Gross, B. and Srawley, J. E., "Analysis of Radially Cracked Ring Segments Subject to Forces and Couples," _Developments in Fracture Mechanics Test Methods Standardization, ASTM STP 632_, W. F. Brown, Jr., and J. F. Kaufman, Eds., American Society for Testing and Materials, 1977, pp. 39-56.

4. Underwood, J. H., Scanlon, R. D., and Kendall, D. P., "K Calibration for C-Shaped Specimens of Various Geometries," _Fracture Analysis, ASTM STP 560_, American Society for Testing and Materials, 1974, pp. 81-91.

5. Underwood, J. H., and Kendall, D. P., "K Results and Comparisons for a Proposed Standard C-Specimen," Benet Weapons Laboratory Technical Report WVT-TR-74041, Watervliet, NY, September 1974.

6. Underwood, J. H., unpublished data.

7. Tada, H., Paris, P. C., and Irwin, G. R., _The Stress Analysis of Cracks Handbook_, Del Research Corporation, Hellertown, PA, 1973.

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
COMMANDER	1
CHIEF, DEVELOPMENT ENGINEERING BRANCH	1
ATTN: DRDAR-LCB-DA	1
-DM	1
-DP	1
-DR	1
-DS	1
-DC	1
CHIEF, ENGINEERING SUPPORT BRANCH	1
ATTN: DRDAR-LCB-SE	1
-SA	1
CHIEF, RESEARCH BRANCH	2
ATTN: DRDAR-LCB-RA	1
-RC	1
-RM	1
-RP	1
CHIEF, LWC MORTAR SYS. OFC.	1
ATTN: DRDAR-LCB-M	1
CHIEF, IMP. 81MM MORTAR OFC.	1
ATTN: DRDAR-LCB-I	1
TECHNICAL LIBRARY	5
ATTN: DRDAR-LCB-TL	
TECHNICAL PUBLICATIONS & EDITING UNIT	2
ATTN: DRDAR-LCB-TL	
DIRECTOR, OPERATIONS DIRECTORATE	1
DIRECTOR, PROCUREMENT DIRECTORATE	1
DIRECTOR, PRODUCE ASSURANCE DIRECTORATE	1

NOTE: PLEASE NOTIFY ASSOC. DIRECTOR, BENET WEAPONS LABORATORY, ATTN: DRDAR-LCB-TL, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES		NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH & DEVELOPMENT ATTN: DEP FOR SCI & TECH THE PENTAGON WASHINGTON, D.C. 20315	1	COMMANDER US ARMY TANK-AUTMV R&D COMD ATTN: TECH LIB - DRDTA-UL MAT LAB - DRDTA-RK WARREN MICHIGAN 48090	1 1
COMMANDER US ARMY MAT DEV & READ. COMD ATTN: DRCDE 5001 EISENHOWER AVE ALEXANDRIA, VA 22333	1	COMMANDER US MILITARY ACADEMY ATTN: CHMN, MECH ENGR DEPT WEST POINT, NY 10996	1
COMMANDER US ARMY ARRADCOM ATTN: DRDAR-LC -LCA (PLASTICS TECH EVAL CEN) -LCE -LCM -LCS -LCW -TSS(STINFO) DOVER, NJ 07801	1 1 1 1 1 1 2	COMMANDER REDSTONE ARSENAL ATTN: DRSMI-RB -RRS -RSM ALABAMA 35809	2 1 1
COMMANDER US ARMY ARRCOM ATTN: DRSAR-LEP-L ROCK ISLAND ARSENAL ROCK ISLAND, IL 61299	1	COMMANDER ROCK ISLAND ARSENAL ATTN: SARRI-ENM (MAT SCI DIV) ROCK ISLAND, IL 61202	1
DIRECTOR US Army Ballistic Research Laboratory ATTN: DRDAR-TSB-S (STINFO) ABERDEEN PROVING GROUND, MD 21005	1	COMMANDER HQ, US ARMY AVN SCH ATTN: OFC OF THE LIBRARIAN FT RUCKER, ALABAMA 36362	1
COMMANDER US ARMY ELECTRONICS COMD ATTN: TECH LIB FT MONMOUTH, NJ 07703	1	COMMANDER US ARMY FGN SCIENCE & TECH CEN ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER US ARMY MOBILITY EQUIP R&D COMD ATTN: TECH LIB FT BELVOIR, VA 22060	1	COMMANDER US ARMY MATERIALS & MECHANICS RESEARCH CENTER ATTN: TECH LIB - DRXMR-PL WATERTOWN, MASS 02172	2

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT)

	NO. OF COPIES		NO. OF COPIES
COMMANDER US ARMY RESEARCH OFFICE P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709	1	COMMANDER DEFENSE TECHNICAL INFO CENTER ATTN: DTIA-TCA CAMERON STATION ALEXANDRIA, VA 22314	12
COMMANDER US ARMY HARRY DIAMOND LAB ATTN: TECH LIB 2800 POWDER MILL ROAD ADELPHIA, MD 20783	1	METALS & CERAMICS INFO CEN BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
DIRECTOR US ARMY INDUSTRIAL BASE ENG ACT ATTN: DRXPE-MT ROCK ISLAND, IL 61201	1	MECHANICAL PROPERTIES DATA CTR BATTELLE COLUMBUS LAB 505 KING AVE COLUMBUS, OHIO 43201	1
CHIEF, MATERIALS BRANCH US ARMY R&S GROUP, EUR BOX 65, FPO N.Y. 09510	1	MATERIEL SYSTEMS ANALYSIS ACTV ATTN: DRXSY-MP ABERDEEN PROVING GROUND MARYLAND 21005	1
COMMANDER NAVAL SURFACE WEAPONS CEN ATTN: CHIEF, MAT SCIENCE DIV DAHLGREN, VA 22448	1		
DIRECTOR US NAVAL RESEARCH LAB ATTN: DIR, MECH DIV CODE 26-27 (DOC LIB) WASHINGTON, D. C. 20375	1 1		
NASA SCIENTIFIC & TECH INFO FAC P. O. BOX 8757, ATTN: ACQ BR BALTIMORE/WASHINGTON INTL AIRPORT MARYLAND 21240	1		

NOTE: PLEASE NOTIFY COMMANDER, ARRADCOM, ATTN: BENET WEAPONS LABORATORY, DRDAR-LCB-TL, WATERVLIET ARSENAL, WATERVLIET, N.Y. 12189, OF ANY REQUIRED CHANGES.